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(54) **DETERMINING ELECTRIC FIELD CHARACTERISTICS OF LASER PULSES**

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356/457, 484, 485  
See application file for complete search history.

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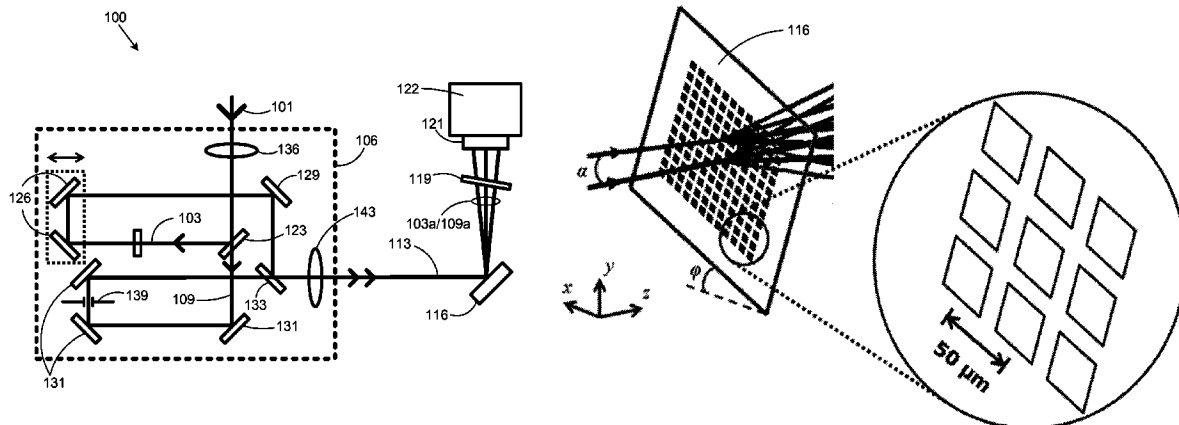
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(57) **ABSTRACT**

Various systems and methods for analysis of optical pulses are provided. In one embodiment, an optical system is provided having an optical axis. The optical system includes a two-dimensional diffraction grating positioned along the optical axis, and a spectral filter positioned along the optical axis after the two-dimensional diffraction grating. The spectral filter is angularly offset about a vertical transverse angle associated with the optical system. The diffraction grating is angularly offset about the optical axis relative to the spectral filter, and an optical capture device positioned after the spectral filter.

**20 Claims, 10 Drawing Sheets**



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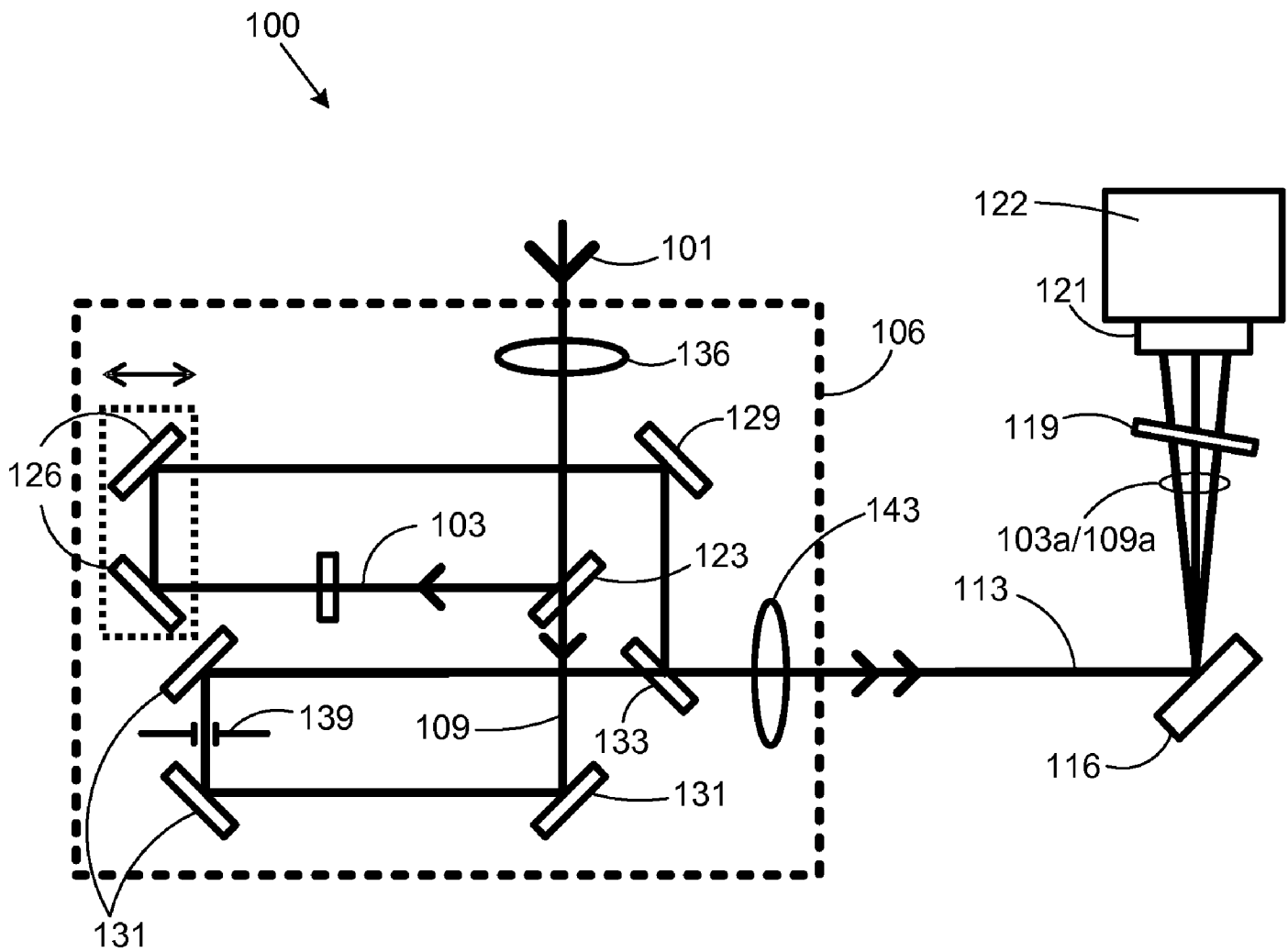
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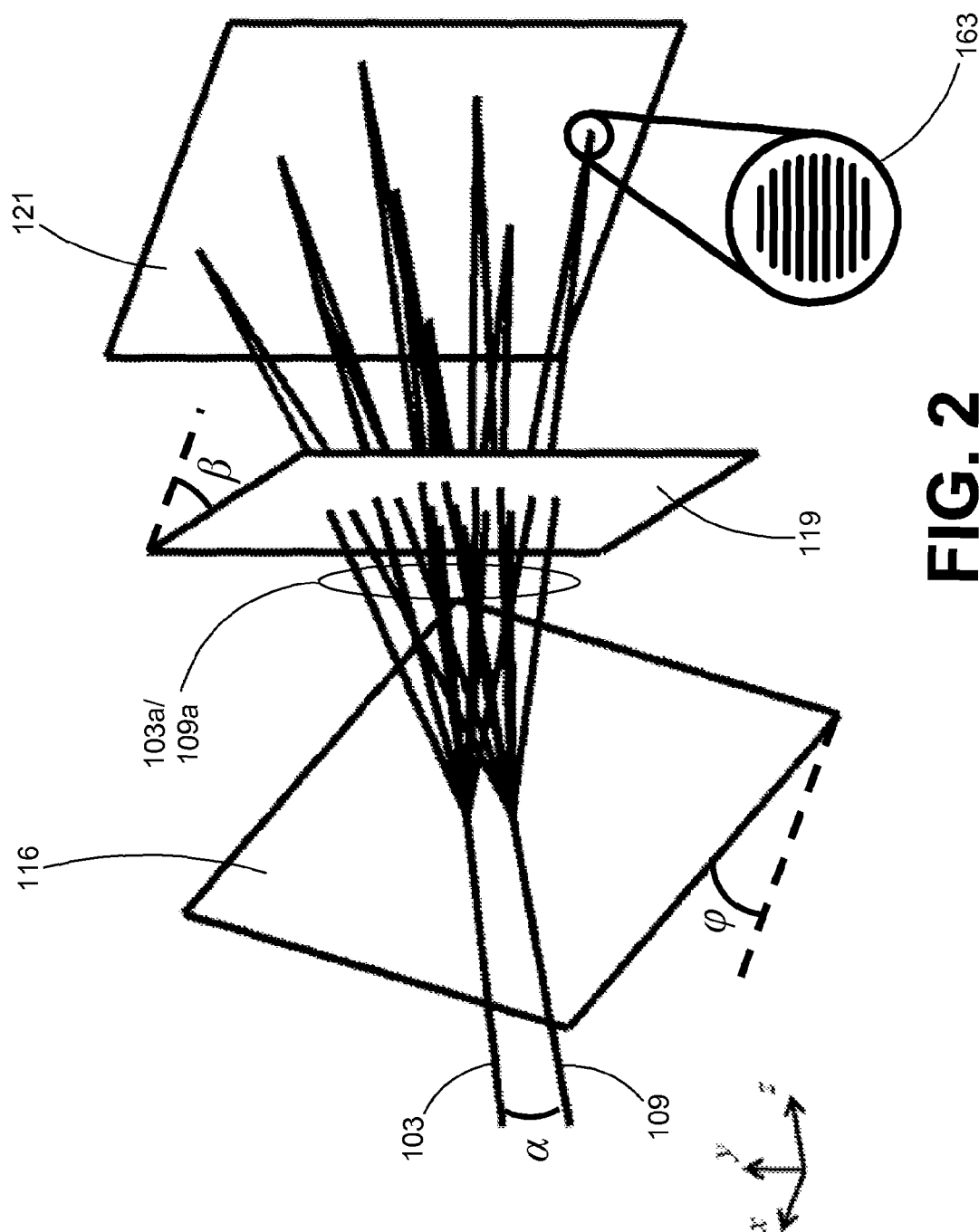
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**FIG. 1**



**FIG. 2**

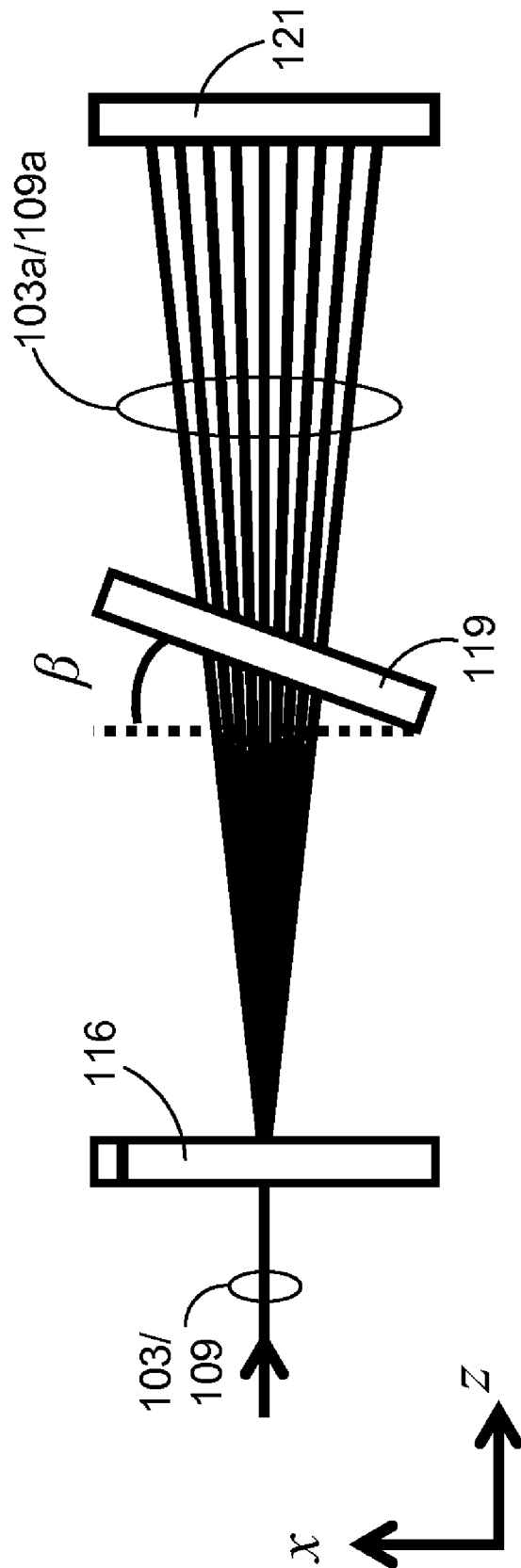


FIG. 3

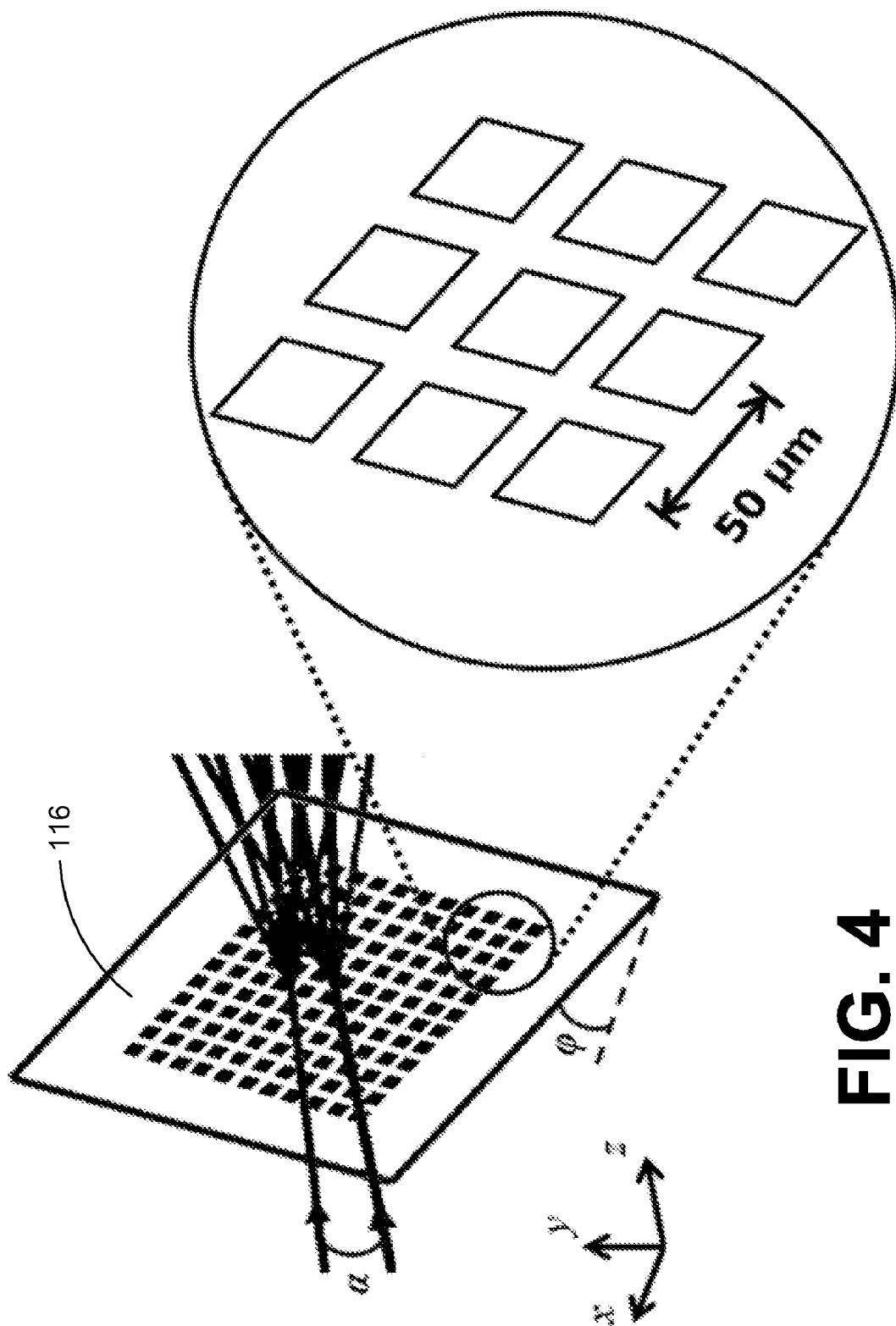


FIG. 4

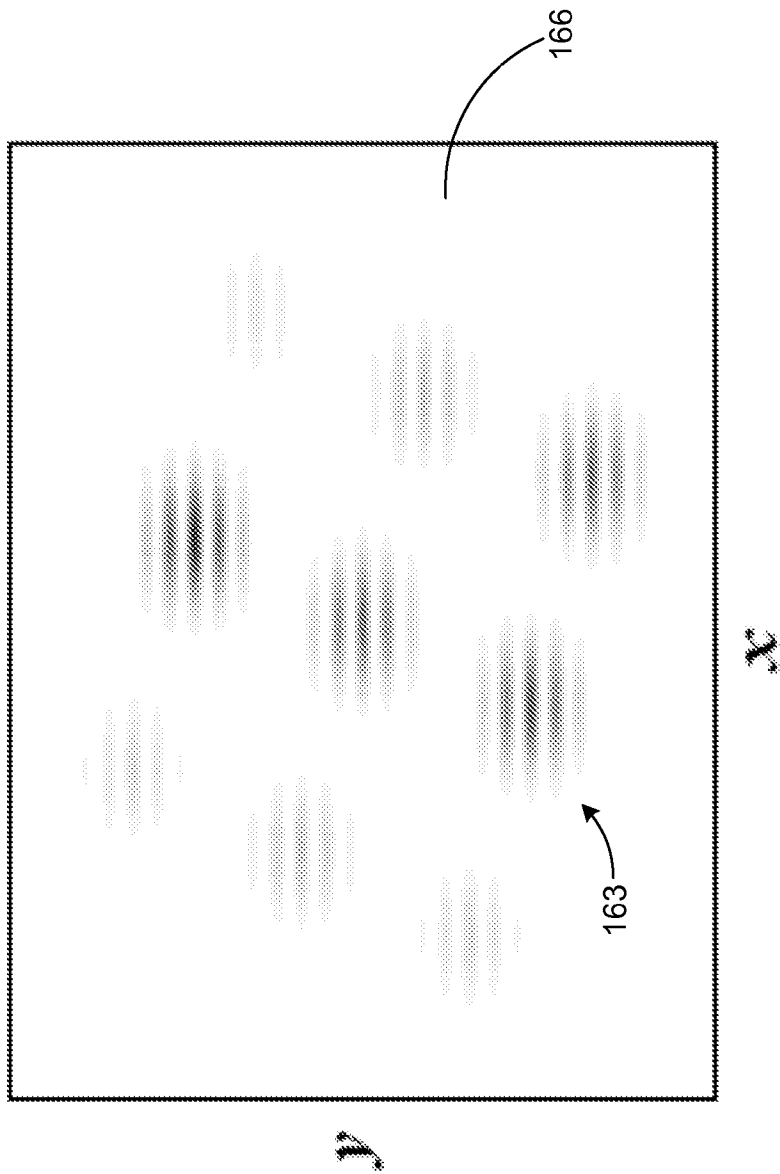


FIG. 5



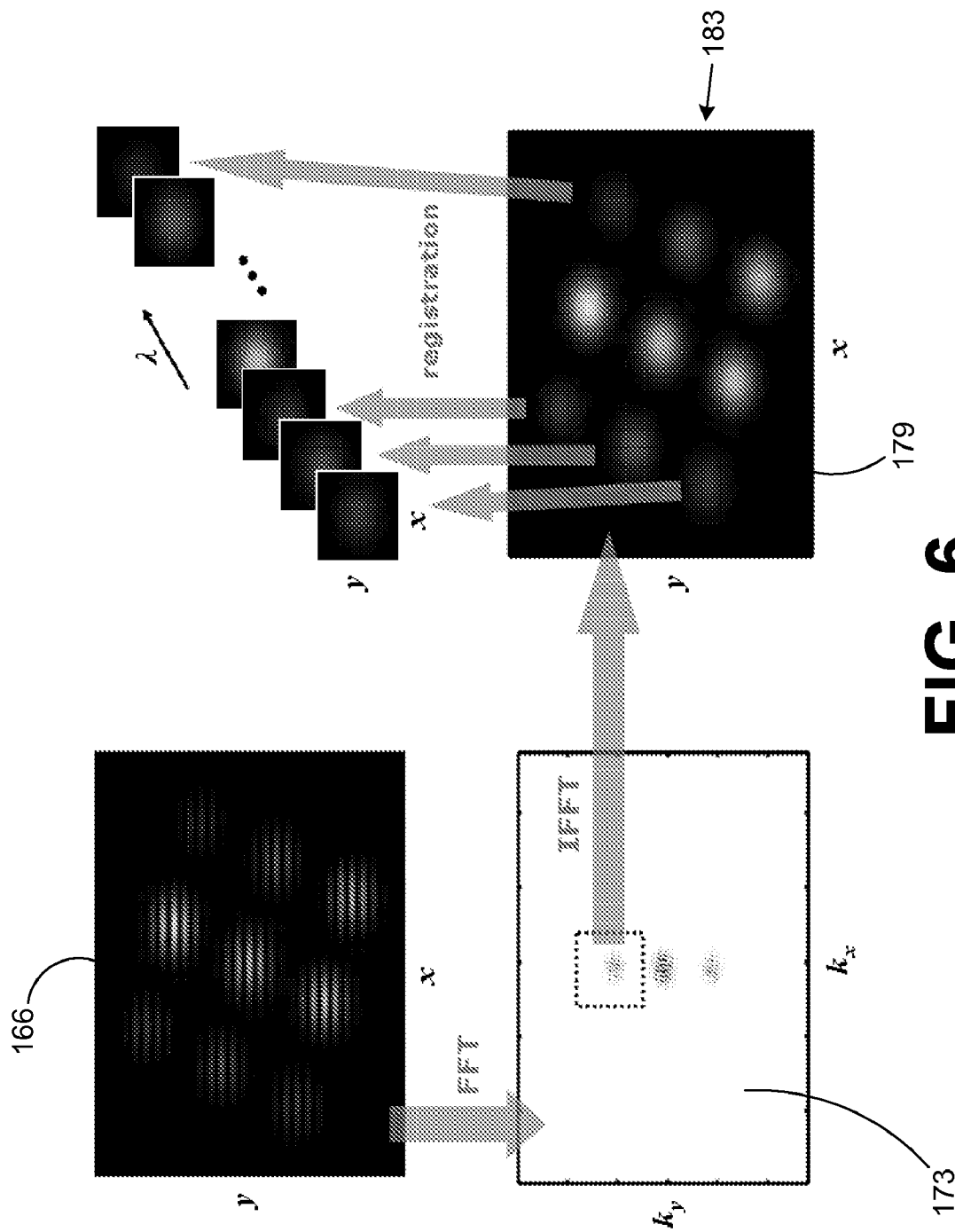


FIG. 6

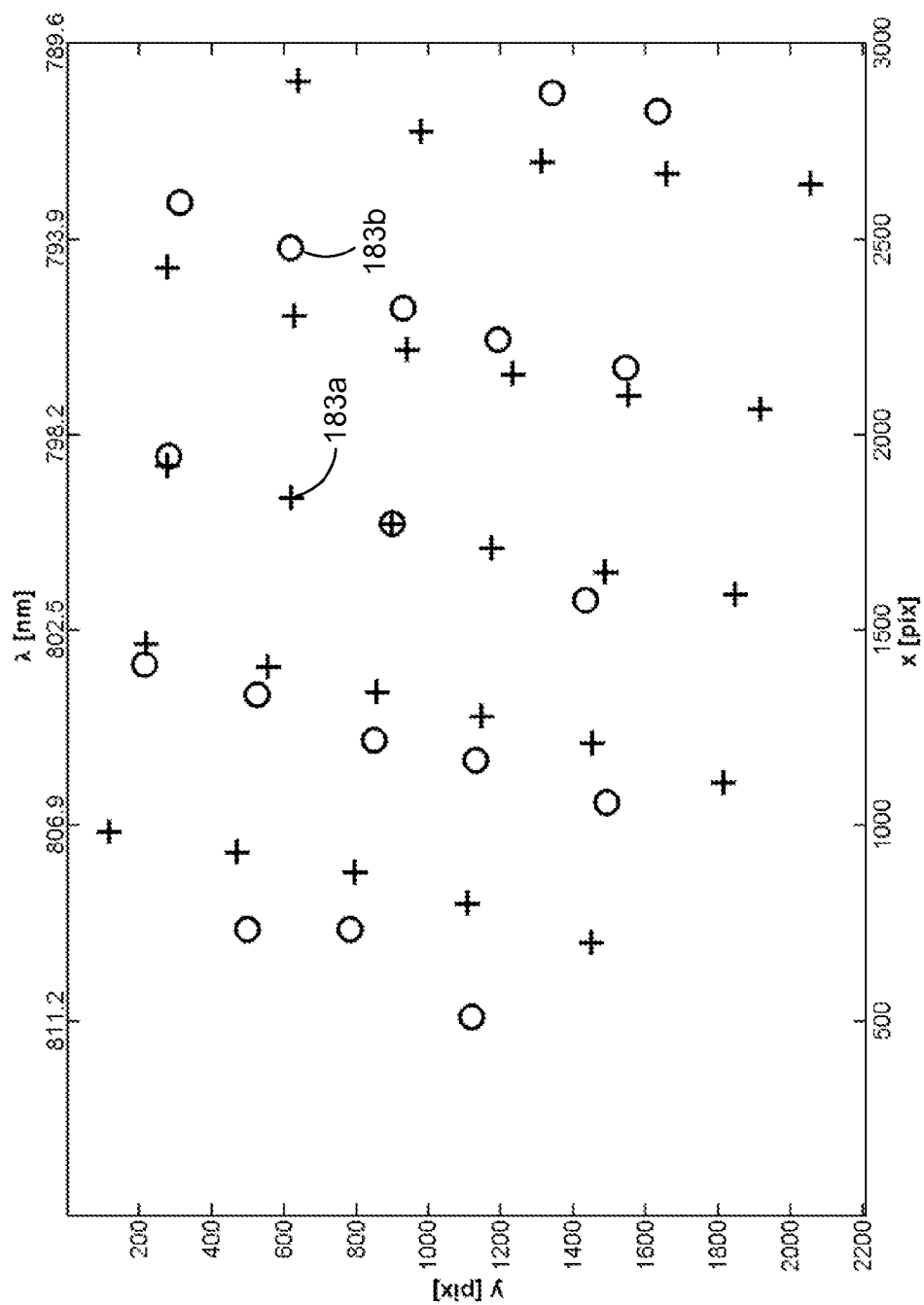


FIG. 7

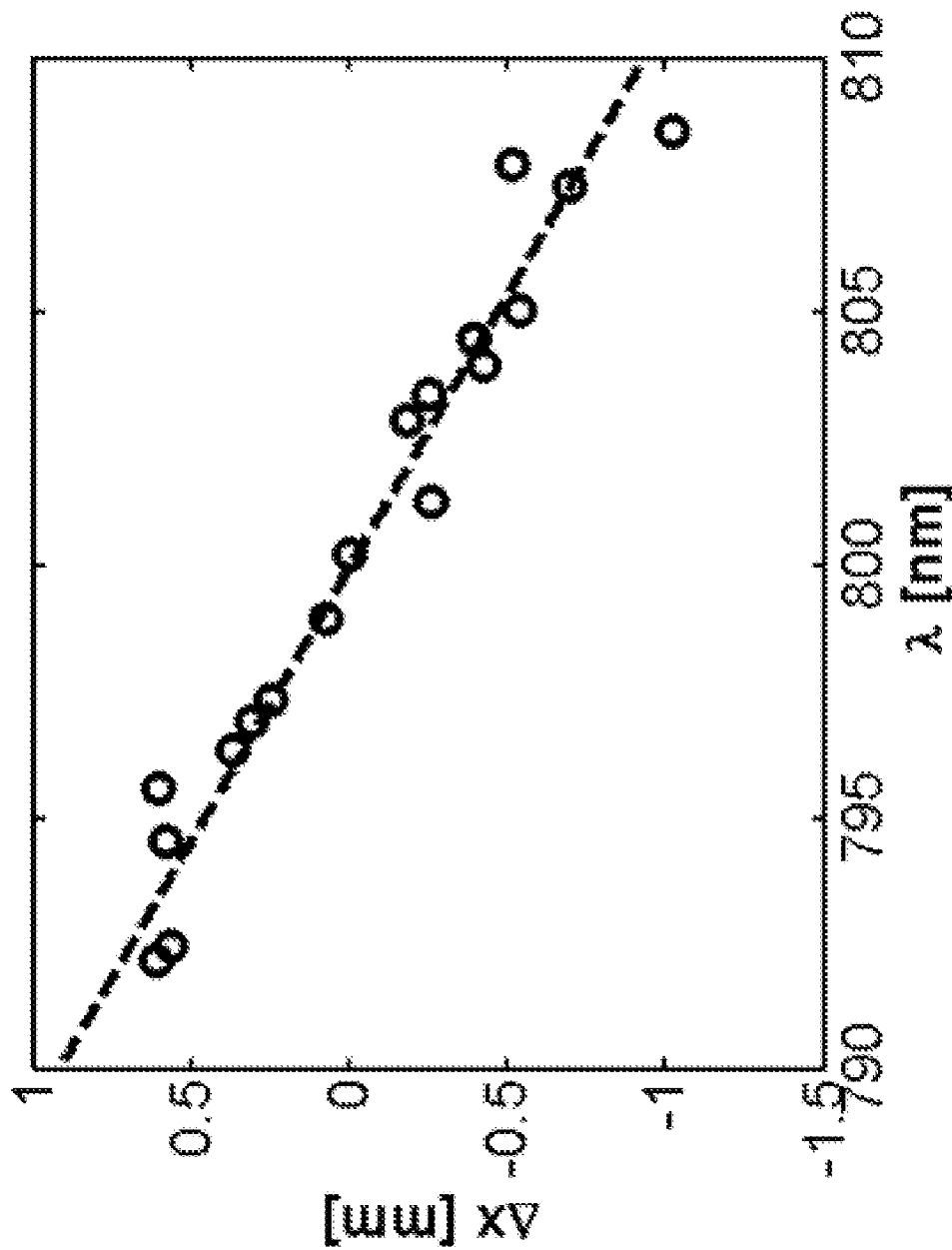
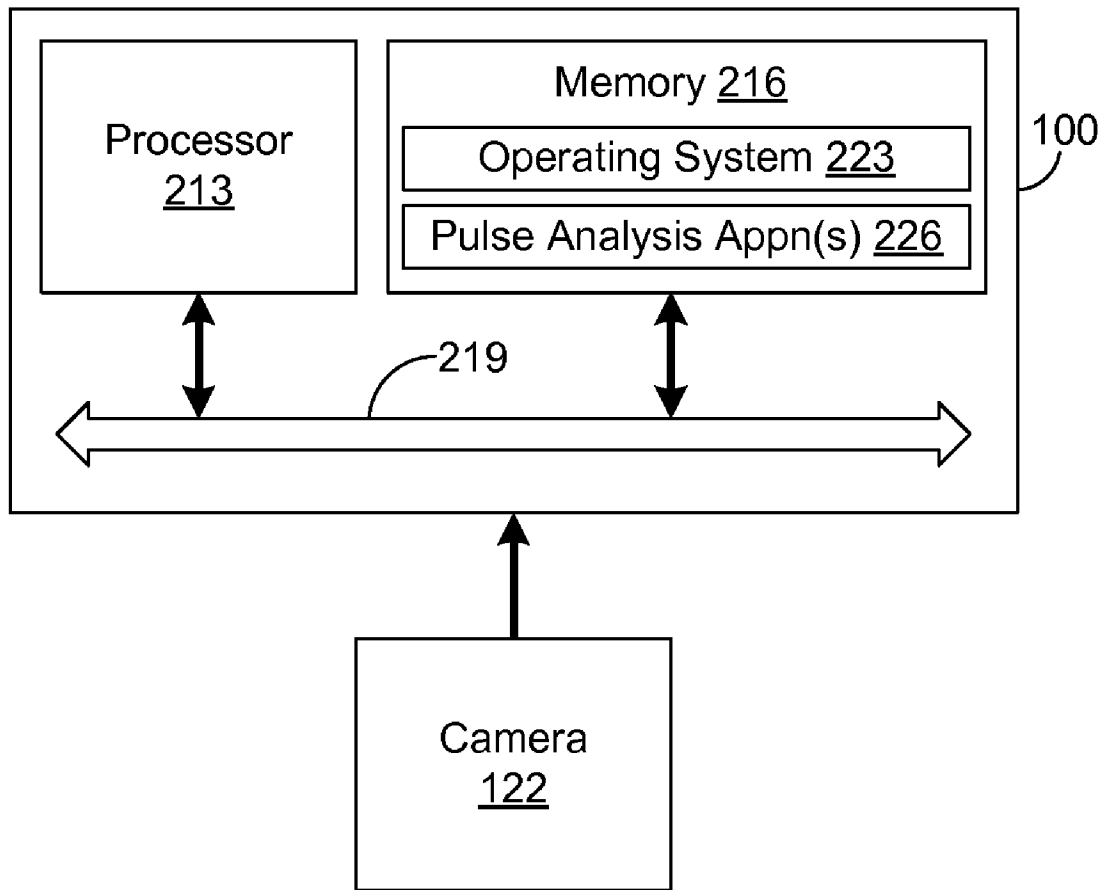
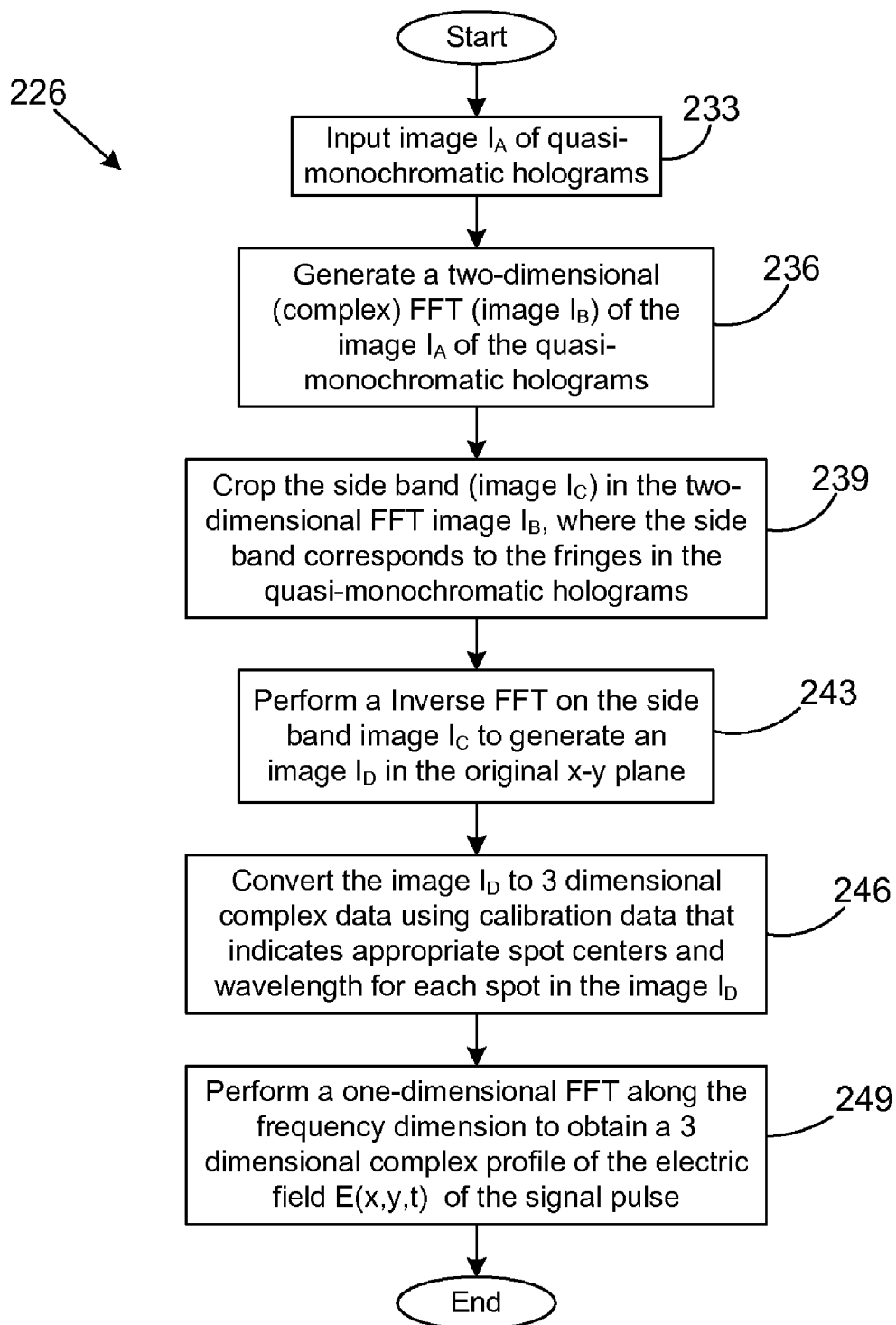


FIG. 8

**FIG. 9**

**FIG. 10**

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## DETERMINING ELECTRIC FIELD CHARACTERISTICS OF LASER PULSES

### STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The U.S. government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of grant number ECS-0200223 awarded by the National Science Foundation of the United States.

### BACKGROUND

In ultrafast optics laboratories it is often desirable to measure the spatial or temporal profile of ultrashort pulses. In some situations, separate spatial and temporal measurements are insufficient in order to obtain the desired profile, and complete spatio-temporal dependence of the pulse is needed. For example, a pulse can be contaminated by spatio-temporal distortions that limit the performance of an ultrafast system such as might be the case, for example, with amplified pulses. Alternatively, the pulse may have been used to excite or probe complex media with time-varying spatial structure. Indeed, spatial-temporal distortions are quite common, and only very carefully and precisely aligned pulses can be considered to be free of such distortions. Unfortunately, such precisely aligned pulses are generally obtained at significant cost and effort.

### BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. 1 is drawing an optical system employed to determine electric field characteristics of a laser pulse according to an embodiment of the present invention;

FIG. 2 is a drawing of a portion of the optical system of FIG. 1 according to an embodiment of the present invention;

FIG. 3 is a drawings of a top view of the portion of the optical system depicted in FIG. 2 according to an embodiment of the present invention;

FIG. 4 is a drawing of a two-dimensional grating employed in the portion of the optical system depicted in FIG. 2 according to an embodiment of the present invention;

FIG. 5 is an example of an image that is generated by the optical system of FIG. 1 according to an embodiment of the present invention;

FIG. 6 is a drawing that illustrates processing of the image of FIG. 5 in order to obtain characterize the electric field of the signal pulse used to generate the image of FIG. 5 according to an embodiment of the present invention;

FIG. 7 is a drawing that provides one illustration of the plot of the centers of an image generated from the image of FIG. 5 as compared to the plot of information from a calibration pulse according to an embodiment of the present invention;

FIG. 8 is a drawing that illustrates a degree of spatial chirp in the signal pulse that generated the image of FIG. 5 according to an embodiment of the present invention;

FIG. 9 is a block diagram of one example system that is employed to process the image of FIG. 5 in order to obtain

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characterize the electric field of the signal pulse used to generate the image of FIG. 5 according to an embodiment of the present invention; and

FIG. 10 is one example of a flow chart of the system or method implemented in order to process the image of FIG. 5 according to an embodiment of the present invention.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, shown is an optical system **100** according to an embodiment of the present invention. As an input, the optical system **100** receives an input signal pulse **101**. The optical system **100** includes optical elements **106** that are configured to separate the input signal pulse **101** into a reference pulse **109** and a signal pulse **103**. The optical elements **106** align the propagation of the reference pulse **109** and the signal pulse **103** along crossing trajectories **113** toward a two-dimensional diffraction grating **116**, a spectral filter **119**, and an image capture device **121** included, for example, in a camera **122** as will be described. The spectral filter **119** may comprise, for example, a band-pass interference filter or other appropriate filter that provides for frequency filtering as will be described below. The image capture device **121** may comprise, for example, a charge coupled device (CCD) array or other image capture device as can be appreciated. As shown in FIG. 1, the crossing trajectories are shown in the same plane due to the top view shown, although the crossing nature of the trajectories is illustrated in later figures to be described.

The signal pulse **101** may comprise, for example, an ultrashort laser pulse such as a pulse generated by a mode-locked laser or an amplifier, with a pulse duration in the femtosecond regime and a pulse energy in the nanojoule to millijoule range. Given that the splitter **123** comprises, for example, a partially silvered mirror (i.e. a 50% silvered mirror), both the signal pulse **103** and the reference pulse **109** are substantial replicas (with half of the power, etc.) of the input signal pulse **101**, until the reference pulse **109** undergoes filtering as will be described.

According to various embodiments, the nature of the full spatio-temporal electric field of the signal pulse **103** is either entirely or partially unknown. The optical system **100** provides for the determination of the full spatio-temporal electric field profile of the signal pulse **103** based on a single pulse. Based on this information, the spatio-temporal electric field of the input signal pulse **101** is determined since the signal pulse **103** is effectively a 50% copy of the input signal pulse **101**.

To this end, the optical elements **106** of the optical system **100** include a splitter **123**, adjustable mirrors **126**, and stationary mirrors **129** and **131**. The optical elements **106** also include a one-sided mirror **133** that allows the reference pulse **109** to pass therethrough while reflecting the signal pulse **103** as shown. The optical elements **106** further include a lens **136** that focuses the input signal pulse **101** from the source.

The reference pulse **109** is filtered by a spatial filter **139**. Such a filter may comprise, for example, a pinhole in the focal plane of a telescope. According to one example embodiment, the pinhole may be 50 microns in diameter, although pinholes of other sizes may be employed depending on the input beam size and the lenses that are chosen.

The optical elements **106** also include a lens **139** through which the signal and reference pulses **103** and **109** are directed as they propagate toward the two-dimensional grating **116**.

Associated with the optical system **100** is an optical axis. The optical axis generally follows the direction of propaga-

tion of the signal/reference pulses **103/109** through the optical system **100** and falls at a center point of each of the optical elements **106**, the two-dimensional diffraction grating **116**, the spectral filter **119**, and the image capture device **121**. In this respect, the optical axis is a term of art as applied to the optical system **100** and other optical arrangements as can be appreciated.

Next, a description of the operation of the optical system **100** is provided. Given that the electric field profile or characteristics of the signal pulse **101** are unknown, it is assumed that one desires to determine such information. Such information may be desired, for example, to aid in the adjustment or calibration of a laser light source or to determine the qualities of a substance through which the signal pulse has passed, etc.

To this end, the input signal pulse **101** is directed along the optical axis of the optical system **100** into the lens **133** and to the splitter **123**. One portion of the input signal pulse **101** is reflected by the splitter **123** to the adjustable mirrors **126**. The adjustable mirrors can be moved along an axis in a single direction as shown to adjust the distance of travel of the signal pulse **103** so as to be able to synchronize the phase of the signal pulse **103** with the phase of the reference signal **109**. The signal pulse **103** is reflected by the adjustable mirrors **126** and the stationary mirror **129** to the one-sided mirror **133**.

The reference pulse **109** that is split from the input signal pulse **101** is directed by mirrors **131** to the one-sided mirror **133**. Along the way, the reference pulse **109** is filtered by the spatial filter **139** to result in a uniform electric field of the reference pulse **109**.

The positioning of the mirrors **131** result in the propagation of the reference pulse **109** in a trajectory that is parallel to a trajectory of the propagation of the signal pulse **103**. The trajectories of the reference pulse **109** and the signal pulse **103** after the one-sided mirror **133** are thus parallel separated by a distance  $d$ .

After the one-sided mirror **133**, the signal and reference pulses **103** and **109** are directed to the lens **143** positioned before the two-dimensional grating **116** that redirects the propagation of the reference pulse **109** and the signal pulse **103** from the parallel trajectories to crossing trajectories directed toward the two-dimensional grating **116**. The crossing trajectories comprise trajectories that are directed toward each other such that they will pass through each other if allowed to proceed to a common point of both trajectories. In one embodiment, the crossing trajectories are symmetric with respect to the optical axis and collide at the optical axis as it passes through the two-dimensional grating **116** and the spectral filter **119**.

The signal and reference pulses **103** and **109** proceed along the crossing trajectories to the two-dimensional grating **116**. The two-dimensional grating **116** separates both the signal and reference pulses **103** and **109** into a plurality of pairs of component signal and reference pulses **103a** and **109a**. The two-dimensional grating **116** is angularly offset by a pre-defined angle  $\phi$  about the optical axis.

The component signal and reference pulses **103a** and **109a** proceed toward the spectral filter **119**. The spectral filter **119** is positioned so that when each respective pair of component signal and reference pulses **103a** and **109a** pass through the spectral filter **119**, each pair is filtered at a frequency band that is unique to the respective pair of component signal and reference pulses **103a** and **109a**. The frequency band is a narrow band of frequencies depending upon where the respective component signal and reference pulses **103a** and **109a** pass through the spectral filter **119**. Each of the pairs of the component signal and reference pulses **103a** and **109a**

intersect at the image capture device **121**, thereby creating a quasi-monochromatic hologram on the image capture device **121** as the result of the interference between the respective component signal and reference pulses **103a** and **109a**.

The hologram generated by each pair of component signal and reference pulses **103a** and **109a** is termed "quasi-monochromatic" because they actually include a small band of frequencies depending upon the filtering performed by the spectral filter **119** rather than being restricted to a single frequency. Given that the band of frequencies associated with each hologram is relatively small, it is termed quasi-monochromatic since there are relatively few frequencies in each hologram, where the information contained in the hologram is effectively rendered monochromatic.

Once the holograms are generated on the image capture device **121**, a two-dimensional Fast Fourier Transform (2DFFT) is applied to the image from the image capture device **121** of the camera **122**. In the Fourier plane, the terms relating to the interference of the respective component signal and reference beams **103a** and **109a** are isolated and transformed back to the original x-y plane. The resulting image includes both the spatial amplitude and phase of each of the quasi-monochromatic holograms. The spatial amplitude and phase is provided, but there is some expense in terms of a loss of vertical spatial resolution. However, this loss is deemed not to be critical. As will be discussed in greater detail below, a registration step is performed to center all of the spatial distributions and to assign the calibrated wavelengths in order to obtain multi-spectral complex data  $E(x, y, \omega)$  of the signal pulse **103**.

Referring to FIG. 2, shown is a view of a portion of the optical system **100** according to an embodiment of the present invention. As shown, the signal pulse **103** and the reference pulse **109** propagate along crossing trajectories toward the two-dimensional grating **116**. The geometry of the crossing trajectories is such that they form an angle  $\alpha$ . Once the signal pulse **103** and the reference pulses **109** collide with the two-dimensional grating **116**, they are separated into the pairs of component signal and reference pulses **103a** and **109a**. The respective pairs of pulses **103a/109a** proceed through the spectral filter **119** and produce the quasi-monochromatic holograms **163**.

The two-dimensional grating **116** is angularly offset about the optical axis of the optical system **100** by an angle  $\phi$ . Also, the spectral filter **119** is angularly offset about a vertical transverse axis associated with the optical system **100** by an angle  $\beta$ . The positioning of the two-dimensional grating **116** relative to the spectral filter **119** as such facilitates the filtering of each pair of pulses **103a/109a** by a band pass filter with a center frequency that is unique for each pair of pulses **103a/109a**. That is to say, each pair of pulses **103a/109a** is filtered by a band pass filter that has a center frequency that is different than the center frequency of the band pass filter for the remaining ones of the pairs of pulses **103a/109a**. This is the case because the positioning of the two-dimensional grating **116** and the spectral filter **119** as such allows each pair of pulses **103a/109a** to pass through the spectral filter **119** at a different horizontal position with respect to the spectral filter, thereby causing each pair of pulses **103a/109a** to be filtered at a different band of frequencies. The filtering of the individual pairs of pulses **103a/109a** in this manner is termed "frequency filtering" as contemplated herein. The use of the two-dimensional grating **116** and the spectral filter **119** as set forth above advantageously provides the ability to create several quasi-monochromatic holograms **163** with a minimum of optical components.

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Referring next to FIG. 3, shown is a top view of the portion of the optical system 100 depicted in FIG. 2 according to an embodiment of the present invention. The top view of FIG. 3 further illustrates the angular offset of the two-dimensional grating 116 about the optical axis of the optical system 100. The top view also further illustrates the angular offset angle  $\beta$  of the spectral filter 119. The angular offset of the spectral filter 119 results in greater vertical separation between the respective locations at which the pairs of pulses 103a/109a pass through the spectral filter 119.

With reference to FIG. 4, shown is one example of the two-dimensional grating 116 that comprises a grid of opaque squares according to one embodiment. According to one example, the two-dimensional grating 116 includes a grid of squares that are positioned at 50  $\mu\text{m}$  intervals, although two-dimensional gratings with other intervals may be employed depending upon the desired spatial separation of the quasi-monochromatic holograms projected onto the image capture device 121 (FIG. 2).

Referring to FIG. 5, shown is an image 166 of the quasi-monochromatic holograms 163 created by interference between respective signal pulses 103a and reference pulses 109a as it would appear on the image capture device 121. The quasi-monochromatic holograms 163 generally include fringes related to the interference between the respective pulses 103a/109a.

Turning then to FIG. 6, shown is an image that illustrates the processing performed after the image 166 of the holograms 163 (FIG. 5) is generated and captured by the image capture device 121. Once the image 166 is captured, a two-dimensional Fast Fourier Transform (FFT) is performed on the image 163, thereby generating the FFT image 173. Next, a sideband 176 of the FFT image 173 is cropped and an inverse Fast Fourier Transform is performed to generate a subsequent image 179 in the original x-y plane. The image 179 is then converted into three dimensional complex data using calibration data that indicates appropriate spot centers and wavelength for each spot 183 in the image 179. Finally, a one-dimensional FFT is performed in the frequency dimension to obtain a 3 dimensional complex profile of the electric field  $E(x, y, t)$  of the signal pulse 103 (FIG. 1). The processing may be performed, for example, using a computer system that runs appropriate programs such as Matlab and other systems as will be described.

Referring next to FIG. 7, shown is a chart 203 that depicts the locations of the spots 183 in the image 179 (FIG. 6) generated by the inverse Fast Fourier Transform of the sideband 176 (FIG. 6) of the FFT image 173 (FIG. 6) according to an embodiment of the present invention. The chart 203 depicts the spots 183a generated by a known pulse with a uniform electric field. Such a pulse is used for purposes of calibration and generally is a pulse with little or no spatial chirp or other anomalies. In particular, the center points of the spots 183a of the calibration pulse are stored in memory for future use in generating three-dimensional complex data from the inverse Fast Fourier Transform of the sideband 176. Both the position of the spot centers and the frequencies associated therewith are stored.

The spots 183b are generated from a signal pulse 103 that is unknown. The spatial chirp of the signal pulse 103 that generates the spots 183b can be determined by plotting the distance between respective pairs of spots 183a and 183b in the x dimension as a function of frequency.

Referring to FIG. 8, shown is a graph that depicts the difference in the x dimension between the respective pairs of spots 183a and 183b (denoted as  $\Delta x$ ) as a function of frequency. The dashed line is a linear fit to the data that is

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used to calculate the value of the spatial chirp. The severity of the slope of the resulting graph corresponds to the severity of the spatial chirp.

Turning then to FIG. 9, shown is a block diagram of a computer system 100 that is attached to the camera 122 according to an embodiment of the present invention. The computer system 100 may comprise, for example, a computer, server, dedicated processing system, or other system as can be appreciated. The computer system 100 may include various input devices such as a keyboard, microphone, mouse, or other device as can be appreciated. The computer system 100 includes a processor circuit having a processor 213 and a memory 216, both of which are coupled to a local interface 219. The local interface 219 may be, for example, a data bus with a control/address bus as can be appreciated.

Stored on the memory 216 and executable by the processor 213 are an operating system 223 and a pulse analysis application(s) 226. The pulse analysis application(s) 226 are executed in order to determine the profile of the electric field  $E(x, y, t)$  of the signal pulse 103 (FIG. 1). The pulse analysis application(s) 226 may comprise, for example, one or more applications executed to perform various functionality. Such applications may comprise, for example, Matlab, LabView or any compiled code.

The components stored in the memory 216 may be executable by the processor 213. In this respect, the term "executable" means a program file that is in a form that can ultimately be run by the processor 213. Examples of executable programs may be, for example, a compiled program that can be translated into machine code in a format that can be loaded into a random access portion of the memory 216 and run by the processor 213, or source code that may be expressed in proper format such as object code that is capable of being loaded into a random access portion of the memory 216 and executed by the processor 213, etc. An executable program may be stored in any portion or component of the memory 216 including, for example, random access memory, read-only memory, a hard drive, compact disk (CD), floppy disk, or other memory components.

The memory 216 is defined herein as both volatile and nonvolatile memory and data storage components. Volatile components are those that do not retain data values upon loss of power. Nonvolatile components are those that retain data upon a loss of power. Thus, the memory 216 may comprise, for example, random access memory (RAM), read-only memory (ROM), hard disk drives, floppy disks accessed via an associated floppy disk drive, compact discs accessed via a compact disc drive, magnetic tapes accessed via an appropriate tape drive, and/or other memory components, or a combination of any two or more of these memory components. In addition, the RAM may comprise, for example, static random access memory (SRAM), dynamic random access memory (DRAM), or magnetic random access memory (MRAM) and other such devices. The ROM may comprise, for example, a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other like memory device.

In addition, the processor 213 may represent multiple processors and the memory 216 may represent multiple memories that operate in parallel. In such a case, the local interface 219 may be an appropriate network that facilitates communication between any two of the multiple processors, between any processor and any one of the memories, or between any two of the memories etc. The processor 213 may be of electrical or optical construction, or of some other construction as can be appreciated by those with ordinary skill in the art.



The operating system **223** is executed to control the allocation and usage of hardware resources such as the memory, processing time and peripheral devices in the computer system **100**. In this manner, the operating system **223** serves as the foundation on which applications depend as is generally known by those with ordinary skill in the art.

Referring next to FIG. **10**, shown is a flow chart that provides one example of the operation of a pulse analysis application **226** according to an embodiment of the present invention. Alternatively, the flow chart of FIG. **10** may be viewed as depicting steps of an example of a method implemented in the computer system **100** to process the image **166** (FIG. **5**) that includes a plurality of quasi-monochromatic holograms **163** (FIG. **5**). The functionality of the pulse analysis application **226** as depicted by the example flow chart of FIG. **10** may be implemented, for example, in an object oriented design or in some other programming architecture. Assuming the functionality is implemented in an object oriented design, then each block represents functionality that may be implemented in one or more methods that are encapsulated in one or more objects. The pulse analysis application **226** may be implemented using any one of a number of programming languages such as, for example, C, C++, or other programming languages.

Beginning with box **233**, the image **166** (FIG. **6**) of the quasi-monochromatic holograms **163** (FIG. **5**) generated and captured by the camera **122** (FIG. **9**) is received in the memory, for example, as an input from the camera **122**. Next, in box **236**, a two-dimensional Fast Fourier Transform (FFT) is performed on the image **163**, thereby generating the FFT image **173** (FIG. **6**). Then, in box **239**, a sideband **176** (FIG. **6**) of the FFT image **173** is cropped that corresponds to the fringes in the quasi-monochromatic holograms **163**.

In box **243** an inverse Fast Fourier Transform is performed to generate a subsequent image **179** (FIG. **6**) in the original x-y plane. Then, in box **246**, the image **179** is then converted into three dimensional complex data using the spot center and wavelength data taken from the calibration pulse as was discussed with reference to FIG. **7**. Thereafter, in box **249**, a one-dimensional FFT is performed in the frequency dimension to obtain a three-dimensional complex profile of the electric field  $E(x, y, t)$  of the signal pulse **103** (FIG. **1**).

Although the example of the pulse analysis application **226** set forth above is depicted as being embodied in software or code executed by general purpose hardware as discussed above, as an alternative the same may also be embodied in dedicated hardware or a combination of software/general purpose hardware and dedicated hardware. If embodied in dedicated hardware, the pulse analysis application **226** can be implemented as a circuit or state machine that employs any one of or a combination of a number of technologies. These technologies may include, but are not limited to, discrete logic circuits having logic gates for implementing various logic functions upon an application of one or more data signals, application specific integrated circuits having appropriate logic gates, programmable gate arrays (PGA), field programmable gate arrays (FPGA), or other components, etc. Such technologies are generally well known by those skilled in the art and, consequently, are not described in detail herein.

The flow chart of FIG. **10** shows the functionality and operation of one example implementation of a pulse analysis application **226**. If embodied in software, each block may represent a module, segment, or portion of code that comprises program instructions to implement the specified logical function(s). The program instructions may be embodied in the form of source code that comprises human-readable statements written in a programming language or machine code

that comprises numerical instructions recognizable by a suitable execution system such as a processor in a computer system or other system. The machine code may be converted from the source code, etc. If embodied in hardware, each block may represent a circuit or a number of interconnected circuits to implement the specified logical function(s).

Although the flow chart of FIG. **10** shows a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of two or more blocks may be scrambled relative to the order shown. Also, two or more blocks shown in succession in FIG. **10** may be executed concurrently or with partial concurrence. In addition, any number of counters, state variables, warning semaphores, or messages might be added to the logical flow described herein, for purposes of enhanced utility, accounting, performance measurement, or providing troubleshooting aids, etc. It is understood that all such variations are within the scope of the present invention.

Also, where the example pulse analysis application **226** comprises software or code, it can be embodied in any computer-readable medium for use by or in connection with an instruction execution system such as, for example, a processor in a computer system or other system. In this sense, the logic may comprise, for example, statements including instructions and declarations that can be fetched from the computer-readable medium and executed by the instruction execution system. In the context of the present invention, a "computer-readable medium" can be any medium that can contain, store, or maintain the pulse analysis application **226** for use by or in connection with the instruction execution system. The computer readable medium can comprise any one of many physical media such as, for example, electronic, magnetic, optical, or semiconductor media. More specific examples of a suitable computer-readable medium would include, but are not limited to, magnetic tapes, magnetic floppy diskettes, magnetic hard drives, or compact discs. Also, the computer-readable medium may be a random access memory (RAM) including, for example, static random access memory (SRAM) and dynamic random access memory (DRAM), or magnetic random access memory (MRAM). In addition, the computer-readable medium may be a read-only memory (ROM), a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other type of memory device.

It should be emphasized that the above-described embodiments of the present invention are merely possible examples of implementations set forth for a clear understanding of the principles of the invention. Many variations and modifications may be made to the above-described embodiment(s) of the invention without departing substantially from the spirit and principles of the invention. All such modifications and variations are intended to be included herein within the scope of this disclosure and the present invention and protected by the following claims.

Therefore, having thus described the invention, at least the following is claimed:

1. A method, comprising the steps of:  
 propagating a signal pulse and a reference pulse along a pair of crossing trajectories; and  
 simultaneously generating a plurality of quasi-monochromatic holograms from the signal pulse and the reference pulse.

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2. The method of claim 1, wherein the step of simultaneously generating the plurality of quasi-monochromatic holograms from the signal pulse and the reference pulse further comprises the steps of:

separating the signal and reference pulses into a plurality of  
pairs of component signal and reference pulses; and  
frequency filtering the respective pairs of component signal  
and reference pulses, wherein each of the quasi-monochromatic  
holograms results from the interference between the corresponding  
pairs of the component signal and reference pulses.

3. The method of claim 1, further comprising the step of splitting an input signal pulse into the signal pulse and the reference pulse.

4. The method of claim 3, further comprising the step of aligning the phase of the signal and reference pulses.

5. The method of claim 3, further comprising the step of filtering the reference pulse with a spatial filter.

6. The method of claim 2, wherein the step of separating the signal and reference pulses into the pairs of component signal and reference pulses further comprises the step of directing the signal and reference pulses through a two-dimensional diffraction grating.

7. The method of claim 6, further comprising the step of angularly offsetting the two-dimensional diffraction grating about an optical axis of an optical system.

8. The method of claim 2, wherein each of the respective pairs of component signal and reference pulses are filtered by a corresponding one of a plurality of predefined pass bands.

9. The method of claim 8, wherein the filtering of each of the corresponding one of the plurality of predefined pass bands is accomplished by propagating the respective pairs of component signal and reference pulses through a spectral filter angularly offset about a vertical transverse axis associated with the optical system.

10. The method of claim 1, further comprising the step of obtaining the spatial intensity and phase of each of the quasi-monochromatic holograms.

11. The method of claim 10, further comprising the step of reconstructing the electric field of the signal pulse in the time domain based upon the spatial intensity and phase of each of the quasi-monochromatic holograms.

12. A optical system having an optical axis, comprising:  
a two-dimensional diffraction grating positioned along the optical axis;

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a spectral filter positioned along the optical axis after the two-dimensional diffraction grating, the spectral filter being angularly offset about a vertical transverse angle associated with the optical system;

the diffraction grating being angularly offset about the optical axis relative to the spectral filter; and

an optical capture device positioned after the spectral filter.

13. The optical system of claim 12, further comprising optical elements configured to split an input signal pulse into a reference pulse and a signal pulse, the optical elements aligning a propagation of the reference pulse and the signal pulse along crossing trajectories toward the two-dimensional diffraction grating and the spectral filter.

14. The optical system of claim 13, wherein the reference pulse is phase aligned with the signal pulse.

15. The optical system of claim 13, wherein the optical elements further comprise a spatial filter positioned along an optical axis associated with the reference pulse.

16. The optical system of claim 13, wherein the optical elements further comprise a plurality of mirrors that are configured to align the propagation of the reference pulse and the signal pulse along parallel trajectories.

17. The optical system of claim 16, further comprising a lens positioned before the two-dimensional grating that redirects the propagation of the reference pulse and the signal pulse from the parallel trajectories to the trajectories.

18. A system, comprising:

means for aligning a propagation of a signal pulse and a reference pulse along a pair of crossing trajectories; and  
means for simultaneously generating a plurality of quasi-monochromatic holograms from the signal pulse and the reference pulse.

19. The system of claim 18, wherein the means for aligning the propagation of the signal pulse and the reference pulse further comprises means for splitting an input signal pulse into the reference pulse and the signal pulse.

20. The system of claim 18, further comprising:

means for determining the spatial intensity and phase of each of the quasi-monochromatic holograms; and  
means for reconstructing the electric field of the signal pulse in the time domain based upon the spatial intensity and phase of each of the quasi-monochromatic holograms.

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